Working Paper No. 684

Central Banking in an Era of Quantitative Easing*

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September 2011

* Presented at the Inaugural SKBI Annual Conference on Financial Economics: "A New Global Financial Landscape," Sim Kee Boon Institute for Financial Economics, Singapore Management University, May 5, 2011. The author is particularly grateful to Ms. Tan Siok Choo, Dr. Stephen Grenville, and Dr. Bandid Nijawathorn for their comments and suggestions.

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ABSTRACT

This paper compares central banking in the era of Bagehot's Rule (1873) and the current era of quantitative easing (QE) and zero (or near-zero) interest rate policy (ZIRP) to suggest that our analytical frameworks need updating. It also proposes some rules for emerging-market central banks to follow today. Bagehot's Rule—that in a financial crisis, the central bank should lend freely against good collateral, and at market interest rates—can no longer apply in an age when the gold standard has been abandoned, hard budget constraints have disappeared, and the national perspective of central banks limits their ability to regulate a shadow banking system that is global in nature. Central banks in reserve currency countries have used QE and ZIRP because the political will to stem excess consumption and raise taxation is lacking. Central banks in emerging markets might avoid the domestic collective-action traps that the deficit countries have fallen into by applying a systems-wide analytical perspective. This would involve privileging diversity, imposing a strict limitation on concentration, the promotion and regulation of the commons, and increased taxation.

Keywords: Bagehot's Rule; Quantitative Easing; Zero Interest Rate Policy; System-Wide Analysis to Central Banking Policies

JEL Classifications: B00, E42, E52, E58, E60

I am grateful to Singapore Management University for inviting me to the Inaugural Sim Kee Boon Institute Annual Conference on Financial Economics, particularly since I am honoring a distinguished civil servant to whom all visitors to Singapore by air should be grateful for the efficient design and construction of Changi Airport.

I speak with some trepidation about central banking in the presence of my mentor and friend, Professor Charles Goodhart and Governor Allan Bollard, as well as many practicing central bankers in this audience. Nevertheless, as a former central banker, financial supervisor and now scholar, I thought it might be constructive to compare central banking in the era of Bagehot's Rule (1873) and the current era of quantitative easing (QE) and zero, or near, interest rates (ZIRP). Needless to say, all views and errors are entirely my own and not associated with any institution that I am associated with.

Allow me to state the key propositions of my lecture today. Finance is a modern, somewhat abstract derivative of the real sector, but its excessive derivation (or leverage) can seriously hurt the real sector, hence it has to be regulated.

The purpose of this paper is to take a 30,000 feet-high perspective and zoom to ground level before our diagnosis. Taking such a high level system-wide and historical review, the 2007-2009 global financial crisis (GFC) was essentially a crisis stemming from overconsumption financed by overleverage.

My simple analysis is that the GFC was the result of cognitive capture by free market ideology that led to lax monetary and fiscal policies and gross under-supervision of finance in the major reserve currency economies. This resulted in a bubble and then a collapse in the turbocharged financial engineering.

The 1997-99 Asian financial crisis (AFC) was a regional financial crisis stemming from an overstretched and insolvent corporate sector that was caught with the double mismatch (in maturity and foreign exchange). In contrast, the main culprits in the GFC were the financial sectors of the US and Europe that were grossly overleveraged and under-supervised.

The AFC was a regional domestic banking crisis that became a crisis of fiat money, because national central bankers could not create foreign exchange to deal with illiquidity simultaneously at the domestic and balance of payments level. The GFC is a crisis of fiat money for the reserve currency issuers, because there is no hard budget constraint on the

ability of the shadow banking system[1] to create fiat money, nor their oversight for systemic stability. There is now a flight into gold and commodities that will not be stemmed until positive real interest rate returns for global money supply and credibility for "hard fiat money" is revived.

I want to state upfront that I am not trying to demonize modern finance, but to state a political dilemma of globalized monetary creation that has not been solved.

I therefore argue that there were three mistakes in central banking during the GFC. The first was flawed methodology of partial analysis, the second a consequence of the first—wrong diagnosis—and the third, wrong prognosis.

My only excuse for making such critical judgments is for the sake of academic discourse and for emerging market central bankers to avoid making the same mistakes. I would be delighted if I were proved wrong.

1. ECOSYSTEM THINKING VERSUS PARTIAL THINKING

In life, if you ask the wrong question, you get the wrong answer. Cognitive capture and blind spots occurred because our generation of policymakers (collectively central banks, bank supervisors, and professional economists, including myself) was trained by mainstream neoclassical theory that assumed that if parts of the system were stable, the system as a whole would be stable. Academic disciplines have become so compartmentalized that specialized academics rarely saw the interconnections between the different disciplines, nor those outside their frame of analysis[2]. Institutional bureaucracies have also become so specialized and fragmented that they protect their own interests and refuse to see problems outside of their jurisdictions, saying that it's the other agencies' or the foreigners' fault.

It is, therefore, not surprising that we have mental and bureaucratic silos that cannot manage finance as Godzillas that are "global in life and national in death." Fragmentation in tunnel vision and interests create collective action traps.

Once we begin to think of financial markets as networks[3], we begin to realize that our current linear, static, and partial analytical framework is inadequate to the task of looking at systemic risks and behavior. For example, Bank of England's ED for Financial Stability

[1] For definition and description, see Financial Crisis Inquiry Commission Report (2011), available at www.fcic.gov.
[2] Not all economists and central bankers fell into this trap of partial analysis, but a lot looked only at flows and ignored balance sheet effects.
[3] See Andrew Sheng, "Financial Crisis and Global Governance: A Network Analysis" in Michael Spence et al., Commission on Growth and Development, Working Paper 67, World Bank, 2010.

Andrew Haldane has recently described banks as ecosystems in order to examine systemic risks from a natural eco-system perspective[4].

It may be useful to examine how central banking has changed in the last two decades. Emerging market central bankers, like myself, learned the art of central banking from the major reserve currency central banks, particularly the Fed, the Bank of England, the Bundesbank, and the Bank of Japan. We learned the three key functions of central banks are the maintenance of monetary stability, financial stability, and the robustness and efficient operations of the payment system[5]. In the advanced markets, however, with very robust payment systems and hitherto strong financial systems, the emphasis in the last two decades has been on monetary stability, specifically devoting more attention towards inflation targeting. The theory was that central banks essentially had one tool, short-term interest rates, and that it was better to be clear about one target, keeping the inflation rate under check. Central banks were given more independence from the ministry of finance and politics and monetary policy became more transparent, with regular briefings on monetary outlooks and financial stability reports, including publication of monetary policy committee minutes.

In order to be highly accountable for monetary stability at the operational level, leading central banks began to either assume that monetary stability would engender financial stability (since the market would take care of itself at the institutional level), or they could assume that financial stability could be taken care of by separate agencies, either institutionally-based financial regulators or super-regulators. The currently fashionable idea of macro-prudential measures was neglected during this period of putting inflation targeting before asset bubbles or other targets such as financial stability, growth, or employment.

At the height of this trend, many central banks followed variants of Taylor's Rule[6], first formulated in 1993, which reduced central bank operations to following specific rules that appeared mechanical in understanding, if not operations. "At their most basic level these policy rules are statements about how government policy actions will react in a predictable way to different circumstances. They can be stated algebraically as in many monetary policy rules such as the Taylor rule, which says that the short-term interest rate should be set by the

[4] Andrew G. Haldane and Robert M. May, "Systemic Risk in Banking Ecosystems," Nature, 20 January 2011, Vol. 469, 351-355.
[5] See Stanley Fischer, "Central Bank lessons from the global crisis," Bank of Israel, 31 March 2011.
[6] See John B. Taylor, "Swings in the Rules-Discretion Balance," Stanford University, November 2010.

central bank to equal one-and-a-half times the inflation rate plus one-half times the GDP gap plus one."

In simple language, central banks should follow transparent, almost mechanical rules.

The handling of the GFC and its aftermath brought these central bankers crashing down to the realities of changing context and the interdependencies between money, credit, financial stability, jobs, and growth. They had to switch from rules to full discretion to deal with the crisis. Tragically, these central bankers failed to appreciate that their industry had evolved into much larger, complex creatures (including shadow banking), failed to appreciate the dangers of financial product and systemic risks, and know that many of their counter-parties were technically illiquid and insolvent at the last minute.

I find it one of the greatest blind spots in recent history that the explosive rise of shadow banking assets to $20 trillion in size was neither measured in monetary aggregates nor for the systemic risk implications. According to US Flow of Funds data, the shadow banks were in 2007, 95.17% larger than the traditional banking system and 44.20% larger than GDP.

These partial and incomplete views of the finance industry meant that when the Great Meltdown came in 2008, Bagehot's Rule was abandoned in favor of massive guarantees, central bank balance sheet expansion, and ZIRP.

Before we go into the diagnosis, we reflect on the difference between Bagehot's Rule and QE, particularly in philosophy and operations.

2. BAGEHOT'S RULE: LIQUIDITY VERSUS SOLVENCY

Stripped down to its essentials, Bagehot's Rule says that in a financial crisis, the central bank should lend freely against good collateral and at market interest rates. I first read Walter Bagehot's *Lombard Street* (1873) in 1986, when I had to handle the deposit taking crisis failure in Malaysia that year, as it was then one of the few books available on central bank action during a banking crisis.

Walter Bagehot was one of the first to understand the pain of the gold standard on fractional banking. Banks can create money through credit extension, but if there was an outflow of gold after a credit boom, banks that did not have enough credit-worthy liquid assets to meet that credit tightening would fail because of illiquidity, but some would fail due to insolvency, particularly if their clients also failed when higher interest rates caused a deflation in asset prices.

The purpose of the central bank as a lender of last resort under the gold standard is to hold large enough gold reserves as a buffer and to lend freely during a period of illiquidity, but against good collateral and market interest rates. This was to flush out bad bankers and to protect the solvency and credibility of the central bank itself. Under such hard budget constraints, the commercial bankers kept fairly large buffers of liquidity and also capital (somewhere between 20-50% of assets) which also required fairly high lending rates to compensate.

The point to remember is that the gold standard had a direct impact on both business and banks. Commercial banks were the disciplinarians on business debt, whilst they had to maintain self-discipline with sufficient capital and liquidity to meet contingencies. In exchange for lender of last resort facilities, commercial banks subjected themselves to regulation by the central bank and to keep statutory reserves/deposits with the central bank.

All this changed with the abandonment of the gold standard. Fiat money had no hard budget constraint since money could be created by net capital inflows (balance of payments), fiscal borrowing, and bank lending. In the last decade, the shadow banks provided the largest credit expansions.

During the GFC, central banks became the lender of last resort, the market maker of last resort, but also the bank-loss underwriter of last resort, specifically when they took toxic assets onto their balance sheets.

By doing so, central banks have become non-elected fiscal agents, undertaking quasi-fiscal obligations on behalf of the public in the name of financial stability. This violates the principle of no taxation without representation. Furthermore, there are no clear guidelines on who should be bailed out and who should not be, and why some of the prime offenders of market discipline should have been bailed out, whilst smaller institutions have become collateral damage.

Moreover, the purchases of sovereign debt by central banks mean that we have moved from fiscalization of debt to debt monetization, which must ultimately have an inflationary cost. We see this initially in the emerging markets, but as their real effective exchange rates rise and commodity prices increase, inflation will resurface in reserve currency countries. Ultimately, monetization of debt is burden sharing through inflation, but this hits the poor particularly hard, worsening inequality.

On the other hand, the largest bailed out financial institutions have become bigger through consolidation of the smaller institutions, whilst the smallest FDIC banks have been

allowed to fail. As Bank of England Governor Mervyn King stated last March, "none of the underlying causes of the current crisis have been removed. The problem of 'too important to fail' banks is still with us. And even more intractable is the challenge of how to reconcile free trade with a stable international monetary and financial system[7]."

It is as if the captain of Titanic II is rescued and rewarded, whilst the captains of smaller ships that capsized in the wake of Titanic II are punished. The current incentive scheme seems to me to be highly questionable.

3. WHY WASN'T BAGEHOT'S RULE APPLIED?

During the 2007-2009 GFC, there was massive liquidity injection into the financial system in order to staunch the crisis. With the collapse of Lehman Brothers, participants in the wholesale funding market could not trust counterparties and began hoarding liquidity, thus freezing up trade finance and real economic activities. The reserve currency central banks had no alternative except to provide massive liquidity injections to replace the lost liquidity. Since some banks were technically insolvent, the central banks took whatever assets were available as repos or collateral, thus inflating their own balance sheets. The decisive policy action was to keep interest rates low, so that there would not be massive deflation of the highly leveraged balance sheet of the financial system. In essence, it was the ZIRP that prevented the financial engineering total meltdown. The central banks did this not out of choice, but because there were very few options and tools left.

It is useful to remind ourselves why this option was possible, whereas no single emerging market central bank would be able to attempt ZIRP without a massive simultaneous foreign exchange crisis. The AFC experience is that massive devaluation would bankrupt any country with net foreign liabilities. The answer is that ZIRP happened as a collective action response almost simultaneously within all four reserve currency regions, so that from a market point of view, there was nowhere that funds could flee en masse into other fiat currencies. There was a certain amount of flight into gold, but it was a flight of smart money, not widespread. The real reason is that the largest reserve currency country had most of its foreign liabilities in its own currency, and all four did not fear exchange rate devaluation (and may well have welcomed it).

[7] Mervyn King, "Do we need an International Monetary System?" Economic Summit at Stanford Institute for Economic Policy Research, Bank of England, 11 March 2011, p.7, available at www.bankofengland.co.uk/publications/speeches

In other words, ZIRP is not an option for most emerging central bank countries, without inviting big inflation, asset bubbles, or large foreign exchange outflows. ZIRP is a privilege of reserve currency issuers.

Using the lens of systems thinking, it has become obvious that ZIRP is the logical and inevitable outcome of the procyclical feedback loop of financial engineering creating fiat money without hard budget constraints, set off by the historical forces of globalization, deregulation, technology, and financial innovation/engineering.

I would argue that mainstream neoclassical thinking was so imbued with the era of hard money, that it assumed that the monetary world had automatic stabilizing or negative feedback. You cannot print gold, so prices and credit stabilized back to equilibrium. But financial market liberalization and technology allowed financial transactions to be speeded up faster and faster, facilitated by almost zero transaction costs and no automatic stabilizers like dynamic haircuts or collateral margins. The result was that financial derivation increased shadow banking and system leverage without central bank oversight in either monetary creation or financial stability/systemic risk terms.

A nonlinear, reflexive examination of the financial engineering feedback loop would show how inadequate the toolkit of existing static, linear, and Cartesian view of markets has become.

First, using the Lane-Milessi-Ferreti net foreign asset statistics from the IMF, the net foreign asset increase of the surplus countries, Japan and China, was only $1.2 trillion from 1998-2006, whereas the net foreign liabilities of the deficit countries were $2.6 trillion. As you recall, the major reserve countries still blame the surplus countries for their loss of monetary control, due to the famous savings glut. However, using data from the US Flow of Funds, the total increase in shadow banking credit during the same period was $11.2 trillion, and traditional banking credit was $4.4 trillion, creating a total credit impetus of $15.6 trillion, that drove interest rates lower and lower. In other words, the savings glut of the surplus countries may have contributed the initial impetus to finance deficit country consumption[8], but the larger contribution to loss of monetary control was not controlling the credit multiplier of shadow banks.

Second, for their own reasons, reserve currency central banks were reluctant to intervene to stop the procyclical rise of financial engineering asset bubbles. In simple terms,

[8] This argument is circuitous, because emerging market savings could not have arisen without advanced country consumption of their exports.

the higher the level of financial derivation (from mortgage to CDO2), the higher the embedded leverage and increase in shadow banking credit. The increase in liquidity pushed interest rates lower, which increased the value of the derivative products. The accounting valuation measured the assets above-the-line and effectively placed the counter-part liabilities below-the-line or off-balance sheet. The effect is a short-term increase in financial engineering profit that allowed the management to take large bonuses, whereas the liabilities (and leverage) are largely hidden. The credit rating agencies gave these products credibility by rating them AAA.

Third, many derivatives were netted for the purpose of capital calculations. In practice, it was gross liabilities that had to be met during a crisis, not net liabilities. Netting actually disguised the true leverage in the system.

Fourth, it was central bank lender of last resort function that was the anchor of such feedback loops. The existence of (possible) central bank intervention allowed such procyclical feedback loops to grow, because every time there was a shock, central bank puts gave momentum traders further courage to leverage more.

In sum, it was shadow banking credit that mainly drove market interest rates lower and lower, creating the derivative bubble that benefited all momentum traders and investors, especially the financial engineers that were taking the profits off the table. In the end, finance as a sector (excluding derivatives) was larger than national GDP and central banks had to resort to ZIRP in order to keep the bubble from implosion.

To sum up, financial engineering was the channel whereby credit became turbo-charged, but the real issue is that a financial crisis was the inevitable outcome of the fiat money feedback loop without a hard budget constraint.

The crux of the global fiat money crisis is how we can impose the hard budget constraint on shadow banks creating global fiat money when the tools are mainly national.

We should note that higher capital adequacy is not a constraint on banks, because they already rely on government guarantees as their capital. Furthermore, in a reflexive world where liquidity is driven by the shadow banking credit, the banks can easily raise capital from the stock market, because they generate higher ROE than real sector businesses, due to their higher leverage. In other words, there is a huge pro-cyclical financial engineering feedback loop where banks can create liquidity to enable themselves to raise capital to increase their leverage.

Were there any alternative options available during the GFC?

During the AFC, the crisis central banks actually nationalized all the problem banks,

changed the management, cleaned up the balance sheet and then privatized them once recovery was on the way. Asian governments could do this, because banking franchise was a privilege, not a right.

But so far, what has been achieved is to replace the financial engineering losses by public sector and central banking debt. It is no coincidence that the public debt of the crisis countries during the AFC rose by 50% of GDP, whilst the public debt of the crisis countries during this GFC also rose roughly 50% of GDP. We have not addressed the excess consumption part of the root cause of the GFC.

To be fair, reserve currency central banks took these unconventional monetary policy measures because there was no political agreement to take the pain of adjustment at the fiscal side to stem excess consumption.

Ideally, this generation should pay for this generation's consumption through higher taxes, but vested interests against present pain means that the pain is postponed to future generations through higher public debt, which can only be financed through ZIRP. In other words, QE2 and ZIRP arose from a domestic collective action trap because the deficit countries cannot raise taxation. Since shadow banks are now global and are too big to manage at the national level, we also have a global collective action trap since no country is willing to cede sovereignty to agree on global reserve money, global central banking, global regulation, and global fiscal action.

What can emerging market central banks do in this messy situation?

Unconventional times require unconventional solutions. That is why I feel that we need systems thinking in central banking. Systems thinking tells us that finance is a veil, as it is an abstract derivative of real sector behavior. The fatal flaw of finance is that it is opaque, and its opacity can allow the agents to violate the principal-agent fiduciary trust. Finance became too large to fail, too large to jail, because when it engaged in proprietary trading, it became a principal in its own right and had conflicts of interest with their principals. With proprietary trading (self interest), banks lost incentive to perform their function—imposing hard budget constraint on borrowers, since they make more money from trading assets with apparent lower credit risks. They did not impose self-discipline on themselves and conveniently forgot that their herding created systemic risk.

At some point, finance switched from value added as a service industry to value subtraction. This value subtraction was huge, as it took nearly US$14 trillion of public sector aid to restore stability, putting nations into hock for generations. But individual bankers and financial engineers continue to benefit by propelling the myth that finance is special.

Tragically, cognitive capture prevented public awareness of the behavioral change from trusted fiduciary agent to self-serving principals.

If the veil of money and finance were removed, we would find that a crisis should stop excess consumption and excess leverage, with creative destruction to weed out the value-subtraction participants to allow newer, value-adding participants to emerge.

Ironically, the current finance rescue package has achieved the opposite effect. Shadow banks are still not being regulated, they continue to become more concentrated and the world is still fixated on replacing lost consumption with demands for higher consumption from emerging markets. This is where partial thinking does not add up. Unconventional monetary policy is both time inconsistent and logically inconsistent.

I want to repeat my view that we are facing twin crises—a short-term financial crisis and a medium to long-term global warming crisis. Both stem from unsustainable human consumption of natural resources. Instead of creative destruction, unconventional monetary policy has distorted asset prices and created creative frustration.

4. WHAT SHOULD EMERGING MARKET CENTRAL BANKS DO?

Unconventional situations need unconventional analysis. I shall draw upon systems thinking and environmental economics to draw parallels for analysis of finance[9].

The first lesson to draw from systems thinking is diversity. A system based on monoculture or extreme concentration can be extremely fragile. Hence, emerging markets should not be afraid to take different paths. When everyone is going for more consumption and leverage, for the system to be stable, someone must be saving or having higher buffers against tail risks. It may be painful to go against the tide, but in the long run, diverse ideas create innovation and creativity. It is healthy to have diversification and diversity in all systems.

Diversification may also mean strict limitation on concentration, such as anti-trust laws on the financial industry to ensure that markets remain level and fair.

Meadows and more recently, Nobel Laureate Elinor Ostrom, have argued that there are three ways to get out of collective action traps[10]:

[9] The Appendix carries a short brief on systems thinking.

[10] adapted from Donella H. Meadows (2008), pg. 119.

1. Educate everyone to have common values and to work together for the common good. Use social disapproval against anti-commons behavior. This is the classic central banking tool of moral suasion or the bully pulpit.
2. Privatize or socialize the commons. Perhaps public goods should be mutual rather than privatized. For example, clearing houses, rating agencies perform public goods and these can be mutual organizations by users, such as SWIFT. Several of these could be created to compete with each other, without being profit-making, although individual incentives can be enhanced through paying the management market salaries.
3. Regulate the commons, through what Garrett Hardin (the environmentalist who coined the term, Tragedy of the Commons) called "mutual coercion, mutually agreed upon." We may have to use a combination of mutually agreed taxes, such as Tobin tax, carbon tax, and also regulation to deal with distortions in the current financial system.

Indeed, systems thinking induces us to look for leverage points or a place to intervene in a system. Leverage points are places or processes in the system where small changes could lead to large changes in behavior. These leverage points are not always easy to detect and may be largely counterintuitive.

For example, current thinking is that growth will solve all problems. Environmentalists argue that growth may exacerbate our problem of excessive consumption. Rather, it is a question of doing more with less, and to slow down the system so that there is time for self-healing. For example, dynamic transactions taxes, circuit breakers, and bank holidays are used in practice to slow down a market when it panics.

From a systems thinking point of view, the free market is system self-organization. Governments or central banks intervention in the self-organization behavior could either engender pro-cyclical or counter-cyclical behavior. My critique of unconventional monetary policy is that it is in fact pro-cyclical—it has not changed the incentive structure of moral hazard, nor the concentration within the system. If so, unconventional monetary policy has only delayed the pain and not slowed down the positive feedback loop.

Partly because of unconventional monetary policy, we have arrived at a situation of high price distortion, with the price of capital at near zero, the price of labor low due to a large labor supply input from emerging markets and highly inflated prices of capital assets. We will not get back to less distorted prices quickly, but there is no doubt that risk premia in Euro debt markets are beginning to reflect default risks. Hence, slowly but surely, market

forces are reasserting themselves, in spite of central bank intervention.

At the heart of the debate is whether central banks, as agents for monetary discipline, should re-impose the hard budget constraint on global fiat money and by what rule? Or is it impossible to agree on this because what monetary policy that fits the reserve currency economies may not fit those of the rest of the world?

In my view, public opinion is at the cusp of deciding whether to believe in fiat money or to believe in commodity money. If current reserve currency economies do not restore fiscal and monetary discipline, then inflation and the flight into gold will continue. No economy is an island in this highly interconnected world.

Central banking remains an art precisely because it is an anchor of public trust in fiat money.

I do not have all the answers, but I hope the systems thinking approach will lead us towards better understanding of how to respond to a new, post-crisis world.

Penang and Beijing,
29 April 2011.

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APPENDIX:

Systems Thinking: A Mindset Change From Current Mainstream Economic Theory

The following is a crash course on where systems thinking in the natural sciences can help widen perspectives and sharpen thinking on economic and financial systems in contrast to the limiting views embedded in current static, linear, and partial thinking of mainstream economic theory. This framework draws on the work of physicist and later environmentalist Fritjof Capra and the late Donella (Dana) H. Meadows (1941-2001), a scientist and systems analyst who was lead author of the 1972 book "The Limits to Growth."

In The Tao of Physics (1975), University of California Physicist Capra argued that physics had moved beyond Newton towards holistic, relativity thinking that coincided with East philosophies. In Turning Point (1982) he explored paradigms in medicine, biology, psychology and economics and argued that we needed a cross-disciplinary "systems view of life," beyond a mechanistic, Cartesian view of the world. Since the 1980s, a new body of nonlinear complex mathematics has emerged that tried to describe and analyze the complexity of life, called Complexity Theory. Brian Arthur and others have adapted this into complexity economics. In his latest work, The Hidden Connections (2002), Capra attempts a conceptual framework for understanding social structures and behavior that would eventually build ecologically sustainable communities.

As early as 1975, he defined five criteria of systems thinking, different from the old, widely adopted method.

(1) Shift from the parts to the whole. The previous paradigm believed that in any complex system the dynamics of the whole can be understood from the properties of the parts. In the new paradigm, the properties of the parts can be understood only from the dynamics of the whole. Because parts are continuum and changing, what we call a part is merely a pattern in an inseparable web of relationships.

(2) Shift from structure to process. The old paradigm thought that there are fundamental structures, fundamental forces, and mechanisms that interact with each other to give rise to processes. In the new paradigm, every structure is seen as the manifestation of an underlying process. The entire web of relationships is intrinsically dynamic.

(3) Shift from objective science to "epistemic" science. In the old paradigm, scientific descriptions were believed to be objective, i.e., independent of the human observer and the process of knowledge. In the new paradigm, epistemology—the understanding of the process

of knowledge—has to be included explicitly in the description of natural phenomena. Like the Heisenberg Principle in physics, the observer cannot be divorced from the observed.

(4) Shift from building to network as metaphor of knowledge. In the old paradigm, knowledge is seen as a building with fundamental laws and basic building blocks, etc. In the new paradigm, this metaphor is being replaced by that of a network, where reality is seen as a network of relationships, which are constantly interactive and evolving.

(5) Shift from truth to approximate descriptions. The Cartesian paradigm was based on the belief in the certainty of scientific knowledge. In the new paradigm, all scientific concepts and theories are limited and approximate descriptions of reality. This is likened to the Eastern concepts of Zen or enlightenment.

As an environmental economist and systems analyst, Dana Andrews defined a system as an interconnected set of elements that is coherently organized for a function or purpose. A system is more than the sum of its parts, by exhibiting adaptive, dynamic, goal-seeking, self-preserving, self-organizing, and evolutionary behavior. She realized that parts of systems are interconnected through the flow of information, thus changing stocks. The interconnectivity within complex systems means that the least obvious part of the system is often the most crucial determinant of the system's behavior. Systems thinkers understand that systems are made complex by feedback loops, some of which could be positive (destabilizing) or negative (stabilizing). For example, stocks can be buffers to absorb shocks to the system.

Feedback loops mean that there are no simple linear cause and effects (as is found in most economic models), because in the loop, A causes B and B causes change in A, perhaps creating C. In the Chinese Book of Changes, this is called "one creates two (binary), two creates three, and three creates all things." Complexity comes the evolution of very simple functions or processes.

Balancing feedback mechanisms can help stabilize systems but are at the same time resistant to change. These are vested interests or deliberate frictions put into a system to slow down reactions (sand in the wheel).

Because of feedback loops, many relationships in systems are non-linear, creating uncertainty of outcomes. Moreover, because parts of systems are continually evolving, these parts are continuums and do not have clear boundaries. Theoretically, economic concepts are abstract and pure, but in practice, concepts are relative and each is interdependently affected by others, because of externalities. For example, for practical purposes we measure liquidity and solvency separately, but in a crisis, when there is no liquidity, insolvency occurs. Stocks and flows are highly interdependent on each other.

Changing the delay in feedback loops can make the system oscillate towards stability or instability. Complex evolution of systems could lead either to resilience or sustainability or subject to limits, breakdown, or fragility. At any given time, the input that is most important to a system is the one that is the most limiting.

Because human beings are self-interested and have bounded rationality, all human systems have collective action traps or Tragedy of the Commons.

Being aware of system-thinking does not solve all problems, but help us understand how to prevent collective action traps, such as free riding, concentration (winner take all), escalation, low level equilibrium, and seeking the wrong goals.

Meadows teaches us to be humble about making reforms and preventing collective action traps. We need to identify the leverage points in a system, where changes can affect behavior for good or bad. Good leverage points are often counterintuitive. Getting out of Tragedies of the Commons requires either getting shared values or objectives, avoiding getting into the trap, privatizing the commons, or regulating the commons more fairly and equitably.

The counterintuitive leverage point in changing systems caused Capra to talk about the Hidden Connections (2002), because it may very well be the covert rule of behavior (such as politics or illicit money and power) that makes overt rules unenforceable or ineffective.